Science of the Total Environment xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Is long range transport of pollen in the NW Mediterranean basin influenced by Northern Hemisphere teleconnection patterns?

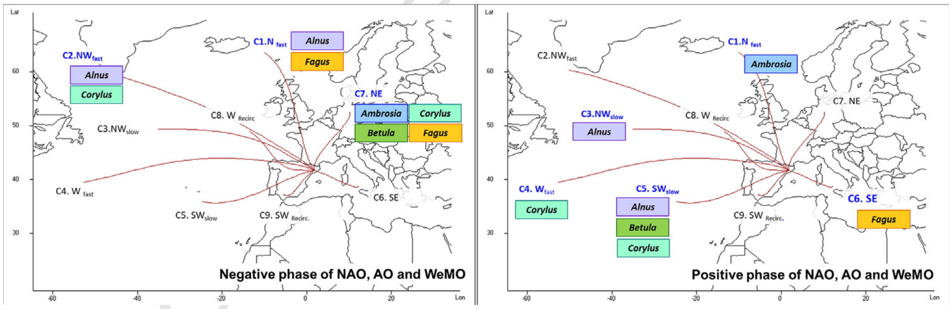
Rebeca Izquierdo [a],*, Marta Alarcon [a], Cristina Periago [a], Jordina Belmonte [b,c]

[a] Departament de Física i Enginyeria Nuclear, Universitat Politècnica de Catalunya, C/Urgell 187, 08036 Barcelona, Spain
[b] Institut de Ciencia i Tecnología Ambientals (ICTA), Universitat Autònoma de Barcelona (UAB). Edifici C, 08193 Bellaterra, Spain
[c] Departament de Biologia Animal, Biologia Vegetal i Ecologia, Universitat Autònoma de Barcelona (UAB). Edifici C, 08193 Bellaterra, Spain

HIGHLIGHTS

- Teleconnection patterns influence atmospheric circulation in Mediterranean basin.
- Effects of climatic variability on airborne pollen transport were examined.
- Pollen transport from Europe was related with negative NAOi, AOi and WeMOi.
- Pollen transport from S and W Europe was linked with positive AOi and WeMOi.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 8 April 2015
Received in revised form 3 June 2015
Accepted 13 June 2015
Available online xxxx

Editor: D. Barcelo

ABSTRACT

Climatic oscillations triggered by the atmospheric modes of the Northern Hemisphere teleconnection patterns have an important influence on the atmospheric circulation at synoptic scale in Western Mediterranean Basin. Simultaneously, this climate variability could affect a variety of ecological processes. This work provides a first assessment of the effect of North Atlantic Oscillation (NAO), Arctic Oscillation (AO) and Western Mediterranean Oscillation (WeMO) on the atmospheric long-range pollen transport episodes in the North-Eastern Iberian Peninsula for the period 1994–2011. *Alnus*, *Ambrosia*, *Betula*, *Corylus* and *Fagus* have been selected as allergenic pollen taxa with potential long-range transport associated to the Northern Hemisphere teleconnection patterns in the Western Mediterranean Basin. The results showed an increase of long range pollen transport episodes of: (1) *Alnus*, *Corylus* and *Fagus* from Western and Central Europe during the negative phase of annual NAO and AO; (2) *Ambrosia*, *Betula* and *Fagus* from Europe during the negative phase of winter WeMO; (3) *Corylus* and *Fagus* from Mediterranean area during the positive phase of the annual AO; and (4) *Ambrosia* from France and Northern Europe during the positive phase of winter WeMO. Conversely, the positive phase of annual NAO and AO are linked with the regional transport of *Alnus*, *Betula* and *Corylus* from Western Iberian Peninsula. The positive phase of annual WeMO was also positively correlated with regional transport of Corylus from this area.

1. Introduction

The atmospheric dynamics in the Western Mediterranean Basin is conditioned by complex interactions of climatic and topographic factors (Millán et al., 1997; Rodríguez et al., 2003; Ulbrich et al., 2012). Indeed,

---

* Corresponding author.
E-mail address: rebeca.izquierdo@upc.edu (R. Izquierdo).

http://dx.doi.org/10.1016/j.scitotenv.2015.06.047
0048-9697/© 2015 Published by Elsevier B.V.

Please cite this article as: Izquierdo, R., et al., Is long range transport of pollen in the NW Mediterranean basin influenced by Northern Hemisphere teleconnection patterns?, Sci Total Environ (2015), http://dx.doi.org/10.1016/j.scitotenv.2015.06.047

the Mediterranean region is among the "Hot Spots" likely to experience major climatic changes in the twenty-first century as a result of the global increase in greenhouse gas concentrations (Giorgi, 2006; IPCC, 2007). Changes in naturally-occurring patterns or "modes" of atmospheric and oceanic variability such as the North Atlantic Oscillation (NAO), the Arctic Oscillation (AO), and the Western Mediterranean Oscillation (WeMO) have an important influence on the temporal variability of atmospheric circulation at synoptic scale and rainfall in Western Mediterranean Basin (Goodess and Jones, 2002; Dünkeloh and Jacobeit, 2003; Martín-Vide and Lopez-Bustins, 2006). Concretely, the Iberian Peninsula, and particularly its Mediterranean fringe, is an area of confluence of several atmospheric patterns acting synchronically with different intensity and effects on precipitation (Gonzalez-Hidalgo et al., 2009; Izquierdo et al., 2014).

At the same time, there is a growing appreciation that changes in the frequency and amplitude of modes of climate variability profoundly influence a variety of ecological processes determining both species density and distribution in a wide range of terrestrial ecosystems (Ottersen et al., 2001; Stenseth et al., 2002; Mysterud et al., 2003; Straile and Stenseth, 2007). Many studies point out the role of phenology as one of the most important bio-indicators to study the direct impact of global change on different species, both at temporal and spatial levels (Menzel et al., 2006; Jochner and Menzel, 2015). In this context, the pollen content in the air offers a quantitative variable to measure the flora phenology and abundance of anemophilous plants.

A lengthening of the active growing season in Europe has been related to increases in winter and spring temperatures, which may in turn be associated with strongly positive indices of NAO (Marshall et al., 2001; Ottersen et al., 2001). The NAO influence on the timing and severity of pollen season has also been detected on different pollen taxa in Northern and Central Europe (D'Odorico et al., 2002), including allergenic pollen as *Betula* and Poaceae (D'Odorico et al., 2002; Stach et al., 2008a,b). However, a NW–SE gradient of spatial differences in the amount of influence exerted by NAO on the timing and magnitude of Poaceae pollen season has been identified in Europe (Smith et al., 2009). Then, the weakest relationship between start dates of Poaceae pollen season and winter averages of the NAO were seen at southern Iberian Peninsula (Smith et al., 2009). Despite the feeblest influence of NAO in the Mediterranean area, the start and the end of pollen season, as well as the peak day of Cupressaceae pollen concentration, were related with phases of NAO in central Italy (Dalla Marta et al., 2011). In addition, a recent study carried on NE Iberian Peninsula showed that years of positive phases of NAO, AO and WeMO indices involved a decrease of annual pollen index, and, at the same time, an advance and enlargement of pollination season for most of 22 pollen taxa considered of high interest due to the abundance, landscape importance and/or allergenic significance in the Western Mediterranean Basin (Izquierdo et al., nd).

Taking into account that airborne pollen concentrations depend both on local flora and atmospheric transport from distant regions, the study of airborne pollen transport may help to comprehend pollen count variations and more accurately predict its atmospheric concentrations (Damialis et al., 2005; Prank et al., 2013). The computation of backward trajectories through the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Draxler et al., 2009) is broadly used to explain atmospheric transport of pollen (Smith et al., 2008; Skjøth et al., 2009; Izquierdo et al., 2011; Zemmer et al., 2012). Cluster analysis has been widely used to categorize back trajectories (Dorling and Davies, 1995; Jorba et al., 2004; Markou and Kassomenos, 2010) and to identify synoptic weather regimes and long-range transport patterns that affect air quality (Cape et al., 2000; Salvador et al., 2007; Valenzuela et al., 2012). Recently, this procedure has been also used for interpreting airborne pollen levels (Makra et al., 2010; Hernández-Ceballos et al., 2011, 2014).

According to the spatial variations observed, further research is necessary to well-understand the influence of NAO and other atmospheric teleconnection patterns on production, release, dispersal and transport of pollen at regional scale, specially the effects on allergenic pollen. The hypothesis of this study is that long range transport (LRT thereafter) of pollen can be partly explained as an effect of the Northern Hemisphere teleconnection patterns. Therefore, the aim here is to study the influence of the main circulation patterns as represented by North Atlantic Oscillation (NAO), Artic Oscillation (AO) and Western Mediterranean Oscillation (WeMO) on 5 pollen taxa with potential LRT collected at 6 localities in Catalonia (NE Iberian Peninsula) during the 18-years period 1994–2011, in order to determine a possible increase of LRT episodes of pollen associated to climate variability which could affect allergenic diseases and the public health.

2. Data & methodology

2.1. Pollen records

Airborne pollen data were recorded by the Aerobiological Network of Catalonia at six stations located in: Barcelona (BCN), Bellaterra (BTU), for the 18-year period 1994–2011, and Girona (GIC), Lleida (LLE), Manresa (MAN), and Tarragona (TAU) for the 16-year period 1996–2011 (Fig. 1). Samples were obtained daily from Hirst samplers (Hirst, 1952), the standardized method in European aerobiological networks, and analyzed following the standardized Spanish method (Galán Soldevilla et al., 2007). The daily pollen concentrations for 5 pollen taxa considered of potential LRT in the Western Mediterranean Basin (Belmonte et al., 2000, 2008a,b; Fernández-Llamazares et al., 2012) have been used: *Alnus*, *Ambrosia*, *Betula*, *Corylus* and *Fagus*. These pollen taxa are regarded of high interest due to their allergenic significance, excepting *Fagus* (Skjøth et al., 2012).

The airborne pollen season has been calculated as the period between the date when the sum of daily mean pollen concentrations reaches 2.5% of the total annual sum and the date when the sum reaches 97.5%; i.e., the time with 95% of the whole pollen amount (Andersen, 1991; Torben, 1991). The seasonal pollen index (SPI) was the sum of the daily pollen concentrations recorded during this period.

2.2. Trajectory computation and cluster analysis

A daily analysis was undertaken based on 96-h isosigma back-trajectories at 12:00 h UTC and 1500 m.a.s.l. at Manresa station, considered by its situation as representative of the synoptic scale circulation features of the Catalan area, by using the HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) 4.0 dispersion model from the Air Resources Laboratory (ARL, available at http://www.arl.noaa.gov/ready/hysplit4.html, Draxler and Rolph, 2003). This height can be taken as representative of the mean atmospheric transport at a synoptic scale within the upper boundary layer (Izquierdo et al., 2014). The meteorological input was obtained from the NCEP (National Center for Environmental Prediction) using the ARL reanalysis database for the 1994–1996 period, the FNL archive for the 1997–2005 period, and the GDAS (Global Data Assimilation System) database for the 2006–2011 period.

Cluster analysis statistically aggregates observations into groups so that each of them is as homogeneous as possible with respect to the clustering variables (Sharma, 1996). To compose each cluster, HYSPLIT has a grouping module based on variations in the total spatial variance between different clusters which is compared to the spatial variance within each cluster component. The final number of clusters is determined by a change in total spatial variance as clusters are iteratively paired (Draxler et al., 2009). This statistical methodology was applied to daily back-trajectories for the period from 1994 to 2011 with the aim to analyze the main atmospheric circulation patterns. The 24 h-time interval was used (thus 4 coordinates each back trajectory of 96-h) to conduct the cluster analysis in a single run.

Please cite this article as: Izquierdo, R., et al., Is long range transport of pollen in the NW Mediterranean basin influenced by Northern Hemisphere teleconnection patterns?, Sci Total Environ (2015), http://dx.doi.org/10.1016/j.scitotenv.2015.06.047

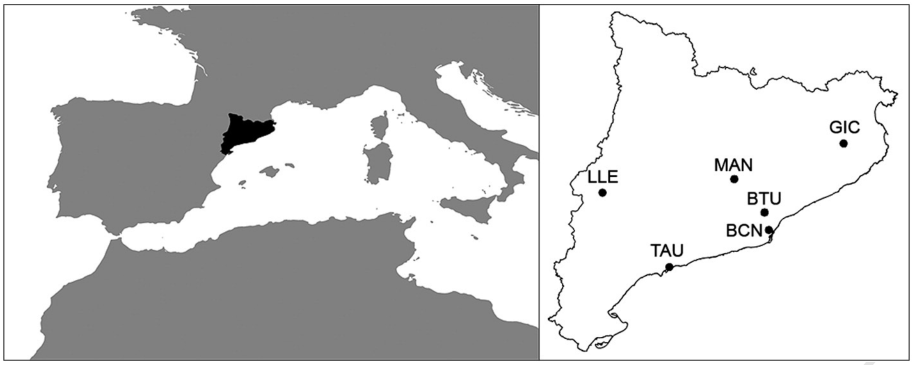


Fig. 1. Study area and sampling stations of the Aerobiological Network of Catalonia.

The cluster pollen index (CPI thereafter), which is defined as the sum of the daily pollen concentrations in each cluster during the airborne pollen season, was also calculated.

2.3. Climatic indices and statistical methods

The strength of the different phases of the NAO is quantified by the NAO index (NAOi), which is based on the difference in the sea level pressure between the sub-polar low-pressure center over Iceland and the subtropical high-pressure center over the Azores (Hurrell, 1995) (available at https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based, The Climate Data Guide: Hurrell North Atlantic Oscillation (NAO) Index (station-based)). In the positive NAO phase strong westerly wind component carries warm moist air over central and north Europe, which results in drier conditions over the Western Mediterranean Basin, whereas this pattern changes in the negative NAO phase with an increase of Atlantic air flows and precipitation.

The AO is quite similar to the NAO, except for the presence of an additional center of action over the NE Pacific (Wallace and Gutzler, 1981; Thompson and Wallace, 1998; Ambaum et al., 2001). The positive phase of the AO brings ocean storms farther north, making the weather drier in the Western Mediterranean Basin. The reverse pattern occurs in the negative AO phase that brings cold and stormy weather to the more temperate regions. Although these two patterns are highly correlated with each other (Thompson and Wallace, 2000; Wallace, 2000), the impact of these two patterns on the precipitation of the Mediterranean regions may be different (Krichak et al., 2014). AO index values were retrieved from de NOAA National Weather Service (NWS) Climate Prediction (CPC, available at http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ao.html).

Finally, the WeMO index consists in the difference between the standardized surface pressure values recorded at Padua (45.40°N, 11.48°E) in N Italy, an area with a relatively high barometric variability due to the influence of the central European anticyclone, and San Fernando (Cádiz) (36.28°N, 6.12°W) in SW Spain, an area often influenced by the Azores anticyclone (available at http://www.ub.edu/gc/English/wemo.htm, Group of Climatology, University of Barcelona). This new secondary oscillation form in the Western Mediterranean Basin was recently introduced in order to explain the rainfall variability in the eastern coast of the Iberian Peninsula, less influenced by the Atlantic fluxes than other Iberian Peninsula zones, due to the complex orography of its surrounding regions (Martín-Vide and Lopez-Bustins, 2006). The WeMO positive phase has been shown to trigger air masses from the Atlantic into the Iberian Peninsula, while its negative phase is associated to flows from the Mediterranean and an increase in the winter precipitation (Lopez-Bustins et al., 2008).

The Spearman's rank correlation coefficient was applied for detection of correlations between the climatic indices and the frequency of air mass flow clusters and the CPI. Because most of the variability patterns of the Northern Hemisphere shows its most relevant dynamics during the winter (Goodess and Jones, 2002; Martín-Vide and Lopez-Bustins, 2006), both annual and winter (December, January, February and March) climatic indices were correlated with pollen data.

SPI varies depending on the pollen taxa, the meteorology of the year and the characteristics of the sampling stations. The mean airborne pollen season for each taxon and sampling station was used. Both, the pollen and climatic indices data used were standardized. Spearman's correlation coefficients were considered significant when $p < 0.05$.

3. Results

3.1. Correlations between the Northern Hemisphere teleconnection patterns and the predominant air mass fluxes in Catalonia

Cluster analysis established 9 back-trajectory groups for the study period 1994–2011 (Fig. 2) which represented the general air mass flows reaching Catalonia in terms of direction and wind speed at 1500 m.a.s.l. The transport regimes were classified as Northern (cluster 1), North-Western (clusters 2, 3), Western (cluster 4), South-Western (cluster 5), South-Eastern (cluster 6), North-Eastern (cluster 7) and Regional recirculation (clusters 8, 9) flows.

Cluster analysis was strongly influenced by the trajectory length, with long trajectories representing fast-moving air masses and short trajectories depicting slow-moving air flows. Among the latter, recirculation flow from SW was the most frequent, accounting for ~20% of the back trajectories (Fig. 2), whereas SE and NW_{fast} flows showed the lowest frequencies, contributing between 6–8%. The rest of clusters ranged between 9% and 13%.

Seasonal cluster frequencies are detailed in Table 1. Recirculation flows from W and SW showed a clear seasonal pattern with the highest frequencies in summer and the lowest in winter, accounting for 19–32% and 7–10% respectively. The opposite dynamics were found for fast flows from W and NW, decreasing from 10–20% in winter to 2–4% in summer. Despite the difference between seasons does not exceed 5%, frequencies of N_{fast} and SE provenances were also lowest in summer (5–9%), and their maximums were observed in spring and autumn (9–14%). Finally, no seasonal patterns were observed for the slow-moving flows from NW, SW and NE, which season frequencies ranged from 8% to 13%.

Table 2 shows the significant correlations obtained between the climatic indices and the air mass provenance frequencies. The W fast flows were positively correlated with winter and annual NAOi ($R \sim 0.6$; $p < 0.05$), winter AOi ($R = 0.55$; $p < 0.05$) and annual WeMOi ($R = 0.65$; $p < 0.05$). Negative correlations were found between N_{fast} vs. the annual AOi ($R = -0.54$; $p < 0.05$), and the SE vs. the annual WeMOi ($R = -0.47$; $p < 0.05$). No correlations were found with the frequency of the other provenances.

Please cite this article as: Izquierdo, R., et al., Is long range transport of pollen in the NW Mediterranean basin influenced by Northern Hemisphere teleconnection patterns?, Sci Total Environ (2015), http://dx.doi.org/10.1016/j.scitotenv.2015.06.047

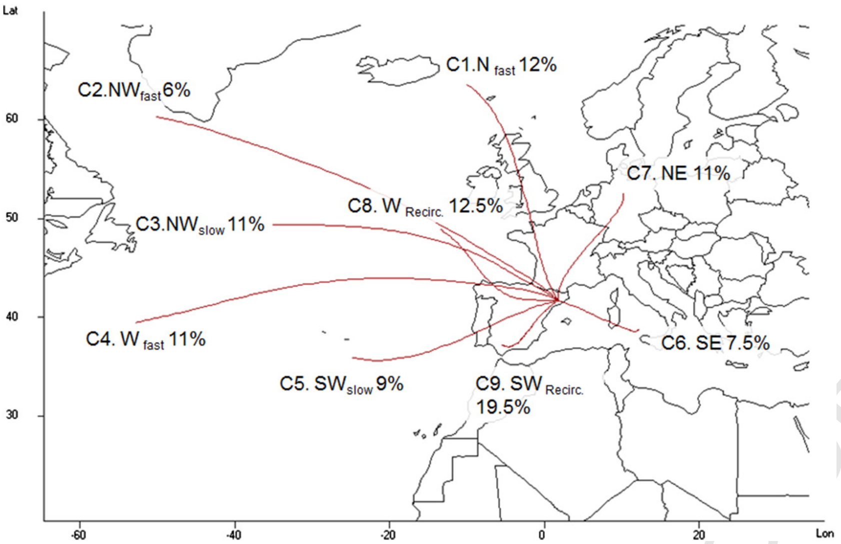


Fig. 2. Cluster centroids and number of back-trajectories (in percentage) associated to each cluster for 1994–2011 period. Back-trajectories (96 h) from the Manresa station, calculated at 1500 m.a.s.l.

3.2. Relationship between climatic indices and pollen transport in Catalonia

The frequency of air mass provenances and the CPI mean of the 6 sampling stations specifically for the airborne pollen season of each taxon are presented in Table 3. Regional recirculation flows showed the highest frequencies for the pollen season of *Ambrosia* (47%), *Betula* (37%) and *Fagus* (38%), however only accounted for 16–29% of their total CPI. Conversely, the less frequent NE flow (7–10%) showed the highest CPI of *Ambrosia* (35%), *Betula* (29%) and *Fagus* (36%). The low frequencies of N_{fast} during the pollen season of *Betula* (12%) and *Fagus* (9%) also recorded high CPI values for these taxa, 22% and 16% respectively. The highest CPI of *Alnus* and *Corylus* (21–23%) were registered by the W_{fast} flows, which frequencies were ~15% in their pollen season. Finally, highlight the low CPI of *Ambrosia* for the Atlantic sector flows (from C1. N_{fast} to C5. SW_{slow}), since with a frequency of 43% only contained the 19% of its total CPI.

The influence of the Northern Hemisphere teleconnection patterns on the dominant atmospheric fluxes may involve LRT of pollen. At the same time, these climate patterns are also associated to variations of weather parameters that may modify pollen dynamics at local level, such as temperature, insolation and precipitation. Hence, the correct interpretation of statistical results is essential, since significant relationships between climatic indices and CPI do not necessarily entail LRT of pollen. The higher the frequency of the air fluxes of a given provenance, the higher possibility of foreign pollen arrivals from this specific provenance. Consequently, higher CPI having the same provenance than the dominant provenance triggered by the modes of the Northern Hemisphere teleconnection patterns has been expected. According to this LRT premise, Spearman's correlations between the climatic indices and CPI of *Alnus*, *Ambrosia*, *Betula*, *Corylus* and *Fagus* at the six sampling stations for the period 1994–2011 were performed (Table 4). To better understand these results, single back-trajectories for the days with pollen presence in the clusters with significant correlations have been also considered.

According with LRT premise, from the 78 significant correlations obtained between the three climatic indices and CPI of *Alnus*, *Ambrosia*, *Betula*, *Corylus* and *Fagus* (Table 4), only 5 of these (superscript 1) agreed with the significant relationships detected between the Northern Hemisphere teleconnection patterns and the air mass provenances (Table 2): (1) the positive correlation between the winter NAOi vs. W_{fast} CPI of *Ambrosia* at Lleida; (2) the negative correlations between the annual AOi vs. N_{fast} CPI of *Alnus* at Tarragona and (3) *Fagus* at Girona; and (4) the positive correlations between the annual WeMOi vs. W_{fast} CPI of *Ambrosia* at Lleida and (5) *Corylus* at Tarragona. The W_{fast} CPI of *Ambrosia* at Lleida was 2.8 pollen grains recorded in 3 days, which accounted for 0.2% of the whole pollen season trajectories (not shown). Consequently, these were considered as isolated LRT episodes (Table 4, superscript 4), independent of the phases of NAO and WeMO and have been excluded for further discussion. On the other hand, the cases in which the sign of the correlation in Table 2 do not coincide with that one in Table 4, indicating disagreement with the LRT premise (Table 4, superscript 3) have also been excluded. This is the case of the

Table 1
Seasonality of atmospheric transport regimes for period 1994–2011. Frequency of back-trajectories associated to each cluster (%). Winter: December–February, spring: March–May, summer: June–August and autumn: September–November.

Season	Annual	Winter (DJF)		Spring (MAM)		Summer (JJA)		Autumn (SON)	
	n	n	%	n	%	n	%	n	%
C1. N_{fast}	786	188	12%	224	14%	155	9%	219	13%
C2. NW_{fast}	390	155	10%	95	6%	29	2%	111	7%
C3. NW_{slow}	742	191	12%	186	11%	180	11%	185	11%
C4. W_{fast}	721	325	20%	174	11%	74	4%	148	9%
C5. SW_{slow}	606	163	10%	155	9%	124	8%	164	10%
C6. SE	489	119	7%	141	9%	90	5%	139	9%
C7. NE	716	193	12%	219	13%	148	9%	156	10%
C8. $W_{Recirc.}$	820	114	7%	190	12%	315	19%	201	12%
C9. $SW_{Recirc.}$	1278	169	10%	265	16%	533	32%	311	19%
Total	6548	1617	100%	1649	100%	1648	100%	1634	100%

Table 2
Spearman's rank correlation coefficients (r_s) between climatic indices and air mass provenance frequencies.

Provenance frequencies (%)	NAOi		AOi		WeMOi	
	Winter	Annual	Winter	Annual	Winter	Annual
C1. N_{fast}	0.06	−0.35	−0.14	−0.54*	0.25	0.11
C2. NW_{fast}	0.29	−0.06	0.33	−0.23	0.06	0.37
C3. NW_{slow}	0.03	−0.10	−0.24	0.11	0.10	0.24
C4. W_{fast}	0.59*	0.58*	0.55*	0.37	0.26	0.65*
C5. SW_{slow}	0.39	0.17	0.41	0.32	0.37	0.44
C6. SE	−0.02	0.20	0.25	0.41	−0.25	−0.47*
C7. NE	−0.34	−0.39	−0.09	−0.43	−0.40	−0.35
C8. $W_{Recirc.}$	−0.02	−0.25	−0.21	−0.06	0.06	−0.28
C9. $SW_{Recirc.}$	−0.23	0.24	−0.07	0.15	−0.12	−0.13

* $p < 0.05$.

Please cite this article as: Izquierdo, R., et al., Is long range transport of pollen in the NW Mediterranean basin influenced by Northern Hemisphere teleconnection patterns?, Sci Total Environ (2015), http://dx.doi.org/10.1016/j.scitotenv.2015.06.047

Table 3

Air mass provenance frequencies and the mean of the sum of the daily pollen concentrations in each cluster (CPI) of the Aerobiological Network of Catalonia stations for the pollen season of *Alnus*, *Ambrosia*, *Betula*, *Corylus* and *Fagus* during period 1994–2011.

Air provenance frequencies	*Alnus* (25Jan–24Apr)		*Ambrosia* (24Jul–5Oct)		*Betula* (23Mar–6Jul)		*Corylus* (16Jan–24May)		*Fagus* (19Apr–11Jun)	
Clusters	n	%	n	%	n	%	n	%	n	%
C1. N_{fast}	243	15%	138	10%	230	12%	307	13%	87	9%
C2. NW_{fast}	138	9%	37	3%	80	4%	172	7%	36	4%
C3. NW_{slow}	192	12%	152	11%	194	10%	272	12%	91	9%
C4. W_{fast}	248	15%	55	4%	136	7%	317	14%	74	8%
C5. SW_{slow}	152	9%	103	8%	178	9%	220	10%	98	10%
C6. SE	115	7%	89	7%	161	8%	178	8%	92	10%
C7. NE	217	13%	134	10%	225	12%	301	13%	120	12%
C8. $W_{Recirc.}$	116	7%	239	18%	279	15%	225	10%	168	17%
C9. $SW_{Recirc.}$	187	12%	380	29%	415	22%	316	14%	199	21%
Total	1608	100%	1327	100%	1898	100%	2308	100%	965	100%
CPI (pollen grains)										
C1. N_{fast}	551	13%	7	7%	586	22%	751	13%	60	16%
C2. NW_{fast}	517	12%	2	2%	131	5%	569	10%	8	2%
C3. NW_{slow}	569	13%	4	4%	295	11%	654	11%	38	10%
C4. W_{fast}	918	21%	2	2%	157	6%	1364	23%	26	7%
C5. SW_{slow}	410	9%	4	4%	116	4%	566	10%	23	6%
C6. SE	179	4%	18	18%	189	7%	718	12%	16	4%
C7. NE	573	13%	36	35%	776	29%	612	11%	135	36%
C8. $W_{Recirc.}$	331	8%	11	11%	181	7%	264	5%	34	9%
C9. $SW_{Recirc.}$	339	8%	18	18%	252	9%	316	5%	34	9%
Total	4388	100%	102	100%	2683	100%	5814	100%	374	100%

negative correlations between the winter NAOi vs. W_{fast} CPI of *Ambrosia* at Bellaterra and *Fagus* at Lleida; as well as the annual WeMOi vs. W_{fast} CPI of *Betula* at Bellaterra, despite that whose provenances showed significant correlations with climatic indices (Table 2). This means that Wfast frequency decreased during negative phases of Northern Hemisphere teleconnection patterns, but at the same time higher CPI was detected from this provenance, which could indicate that an increase of pollen production in the source areas has been occurred. However cases in disagreement with LRT premise also could be related with an increase of local pollen concentrations or precipitation washout effect, consequently only cases according with LRT premise have been taken into account in this study.

Fig. 3 depicts the dynamics of climatic indices and CPI significantly correlated that were according with LRT premise (Table 4, superscript 1). Annual AOi and the percentage, in the Nfast cluster, of *Alnus* pollen at Tarragona and *Fagus* at Girona with respect to the SPI of each taxon, showing opposite dynamics for 1996–2011 period (Fig. 3a). In contrast, annual WeMOi and percentage of *Corylus* pollen in the cluster Wfast at Tarragona with respect to the *Corylus* SPI followed similar dynamics (Fig. 3b). It should be note that there is a high annual variability, with years in which LRT accounted for 36% (*Alnus* at Tarragona) and 45% (*Fagus* at Girona) from Nfast, and 50% (*Corylus* at Tarragona) from Wfast. These percentages ranged between 11–20% for the whole period.

The rest of significant correlations (Table 4) between climatic indices and CPI of *Alnus*, *Ambrosia*, *Betula*, *Corylus* and *Fagus* were also examined in detail and commented below. The taxa in which the sign of the correlation in Table 4 (superscript 2) was in accordance with the sign of the correlation in Table 2, despite that these were non-significant ($r_s > 0.10$, $p > 0.05$; Table 2), were considered in agreement with the LRT premise. On the other hand, the provenances with non-significant correlations and $r_s < 0.10$ (Table 2) were discarded (Table 4, superscript 5), as well as those in which the sign of the correlation showed disagreement with LRT premise and the isolated episodes (Table 4, superscripts 3 and 4).

Taking into account these considerations, Table 4, (superscript 2) shows that winter NAOi was negative correlated with $SW_{Recirc.}$ CPI of *Alnus* at Lleida, and positively with SW_{slow} CPI of *Corylus* at Barcelona. Annual NAOi was positively correlated with SW_{slow} CPI of *Alnus* at Bellaterra, *Betula* and *Corylus* at Girona, and $SW_{Recirc.}$ CPI of *Fagus* at Barcelona; and negatively with NE CPI of *Corylus* at Barcelona and *Fagus* at Bellaterra, and N_{fast} CPI of *Fagus* at Manresa and Tarragona. No correlation were observed for winter AOi. Conversely annual AOi was negatively correlated with NW_{fast} CPI of *Alnus* at Barcelona and *Corylus* at Tarragona; and positively with NW_{slow} CPI of *Alnus* at Barcelona, and SE CPI of *Corylus* at Girona and *Fagus* at Manresa. Winter WeMOi showed positive correlations with N_{fast} CPI of *Ambrosia* at Bellaterra and Manresa; and negative with NE CPI of *Ambrosia* at Bellaterra, *Betula* at Manresa and *Fagus* at Girona. Finally, annual WeMOi was inversely correlated with $W_{Recirc.}$ CPI of *Alnus* at Barcelona, Bellaterra and Girona, *Betula* at Bellaterra and *Corylus* at Girona.

4. Discussion

The atmospheric circulation regimes in the Mediterranean basin show a seasonal cycle, linked to the wet temperate circulation in winter and to the strictly subtropical in summer (Martín-Vide and Lopez-Bustins, 2006). The atmospheric regimes and seasonal patterns at the Iberian Peninsula showed higher frequencies of fast-moving flows from NW and W in winter and slow-moving recirculation flows from W and SW in summer (Fig. 2, Table 1), in concordance with previous studies (Millán et al., 1997; Jorba et al., 2004; Salvador et al., 2008; Izquierdo et al., 2012),.

The relationship between the Northern Hemisphere teleconnection patterns and the main atmospheric circulation pathways was evaluated, with a focus on the NE Iberian Peninsula. The positive correlations between W_{fast} provenance and the three climatic indices (Table 2) confirmed the increase of westerly winds expected during the positive phase of NAO, AO and WeMO (Hurrell, 1995; Thompson and Wallace, 1998; Martín-Vide and Lopez-Bustins, 2006). An increase of N_{fast} flows were linked to the negative phase of AO (Table 2). Besides, the negative WeMOi correlation with SE flow frequency (Table 2) coincided with the increase of humid Mediterranean air-masses related with negative WeMO phase (Martín-Vide and Lopez-Bustins, 2006).

Most of the variability of the Northern Hemisphere teleconnection patterns show its most intensified dynamics during the winter (Visbeck et al., 2001; Goodess and Jones, 2002; Martín-Vide and Lopez-Bustins, 2006). Nevertheless, excepting the negative correlation between winter AOi and W_{fast} flows, the atmospheric pathways described by phases of Northern Hemisphere teleconnection patterns are well represented by the correlation analysis of the climatic indices

Please cite this article as: Izquierdo, R., et al., Is long range transport of pollen in the NW Mediterranean basin influenced by Northern Hemisphere teleconnection patterns?, Sci Total Environ (2015), http://dx.doi.org/10.1016/j.scitotenv.2015.06.047

Table 4
Significant Spearman correlations ($p > 0.05$) between climatic indices and the sum of the daily pollen concentrations in each cluster (CPI) of *Alnus*, *Ambrosia*, *Betula*, *Corylus* and *Fagus* at the Aerobiological Network of Catalonia stations: Barcelona (BCN), Bellaterra (BTU), Girona (GIC), Lleida (LLE), Manresa (MAN) and Tarragona (TAU) during 1994–2011 period. Positive and negative correlations were showed between parenthesis and correlations according with LRT premise were in bold letters.

Pollen taxa	CPI	NAOi		AOi		WeMOi	
		Winter	Annual	Winter	Annual	Winter	Annual
Alnus	C1. N$_{fast}$				**TAU (−)**[a]	LLE (−)[b,c]	
	C2. NW$_{fast}$				**BCN (−)**[b]	BCN, BTU, GIC, MAN (−)[d]	
	C3. NW$_{slow}$		BCN (+)[d]		**BCN (+)**[b]		
	C4. W$_{fast}$						
	C5. SW$_{slow}$		**BTU (+)**[b]				
	C6. SE						
	C7. NE						
	C8. W$_{Recirc.}$					BCN, BTU, LLE (−)[d]	**BCN, BTU, GIR (−)**[b]
	C9. SW$_{Recirc.}$	**LLE (−)**[b]	LLE (−)[b,c]	BTU, LLE (−)[d]			
Ambrosia	C1. N$_{fast}$					**BTU, MAN (+)**[b]	
	C2. NW$_{fast}$			BTU (−)[b,c]		MAN (+)[d,e]	
	C3. NW$_{slow}$						BCN (−)[b,c]
	C4. W$_{fast}$	LLE (+)[1,4],BTU (−)[1,3,4]					LLE (+)[1,4]
	C5. SW$_{slow}$	GIC (−)[b,c]					GIC (−)[b,c]
	C6. SE			LLE (−)[b,c,e]		GIC, MAN (+)[b,c,e]	
	C7. NE					**BTU (−)**[b]	
	C8. W$_{Recirc.}$						
	C9. SW$_{Recirc.}$						
Betula	C1. N$_{fast}$						
	C2. NW$_{fast}$					MAN (+)[d]	
	C3. NW$_{slow}$						
	C4. W$_{fast}$						BTU (−)[1,3]
	C5. SW$_{slow}$		**GIC (+)**[b]				
	C6. SE			BCN (−)[b,c]		GIC (+)[b,c]	
	C7. NE					**MAN (−)**[b]	
	C8. W$_{Recirc.}$						**BTU (−)**[b]
	C9. SW$_{Recirc.}$						
Corylus	C1. N$_{fast}$	BCN,GIC (−)[d]					BCN (−)[b,c]
	C2. NW$_{fast}$	BTU (−)[b,c]			**TAU (−)**[b]	BTU, MAN (−)[d]	
	C3. NW$_{slow}$						
	C4. W$_{fast}$						**TAU (+)**[a]
	C5. SW$_{slow}$	**BCN (+)**[b]	**GIC (+)**[b]				
	C6. SE				**GIC (+)**[b]		
	C7. NE		**BCN (−)**[b]			BTU (+)[b,c]	
	C8. W$_{Recirc.}$	LLE (+)[d]		MAN (+)[b,c]		GIC (−)[d]	**GIC (−)**[b]
	C9. SW$_{Recirc.}$						
Fagus	C1. N$_{fast}$		**MAN, TAU (−)**[b]		**GIC (−)**[a]		
	C2. NW$_{fast}$				BCN (+)[b,c]	TAU (+)[d]	
	C3. NW$_{slow}$						TAU (−)[b,c]
	C4. W$_{fast}$	LLE (−)[1,3,4]					
	C5. SW$_{slow}$	LLE (+)[b,e]	LLE (+)[b,e]	LLE (+)[b,e]	LLE (+)[b,e]		
	C6. SE		LLE (−)[b,c,e]		**MAN (+)**[b]		
	C7. NE		**BTU (−)**[b]			**GIC (−)**[b]	MAN (+)[b,c]
	C8. W$_{Recirc.}$	TAR (+)[d,e]		TAU (+)[b,c,e]			TAU (+)[b,c]
	C9. SW$_{Recirc.}$		**BCN (+)**[b]				

[a] Correlations whose provenances showed significant relationships ($p < 0.05$) in Table 2.
[b] Correlations whose provenances showed non-significant relationships ($p > 0.05$) and $r_s > 0.10$ in Table 2.
[c] Correlations in disagreement with LRT premise.
[d] Correlations whose provenances showed non-significant relationships ($p > 0.05$) and $r_s < 0.10$ in Table 2.
[e] Isolate LRT pollen episodes.

data at an annual timeframe, especially in the case of WeMOi (Table 2). Positive correlations between Atlantic flows vs. winter and annual WeMOi were also observed in Catalonia in a previous study for the period 1984–2012 (Izquierdo et al., 2012). Conversely, no correlation was found in this same study between annual NAOi and annual provenance frequencies and an unexpected positive correlation between annual WeMOi and Mediterranean provenance (Izquierdo et al., 2012). Taking into account that pollen season usually occurred out of winter period, winter and annual climatic indices were correlated with CPI in order to determine the influence level of climatic indices on the main atmospheric transport routes during the pollen season of each pollen taxa. This agrees with previous studies which suggest that the NAO is more likely to affect ecological mechanisms in winter, although the link between winter indices of the NAO and climatic conditions may persist through to summer (Ottersen et al., 2001; Atkinson et al., 2005; Bladé et al., 2012).

Various local and regional environmental drivers affect the timing of flowering and the release processes of pollen (Jato et al., 2002), while synoptic-scale atmospheric condition affect the phenological stages over a region and also determine the transport of the emitted pollen grains from adjacent and remote regions (Veriankaite et al., 2010). The increase of precipitation during negative phase of the three climatic indices at eastern façade of Iberian Peninsula (Martín-Vide and Lopez-Bustins, 2006; Lopez-Bustins et al., 2008; Gonzalez-Hidalgo et al., 2009) could explain the negative relationship between the winter NAOi vs. SW$_{Recirc.}$ CPI of *Alnus* and the annual WeMOi vs. the W$_{Recirc.}$ CPI of *Alnus*, *Betula* and *Corylus* (Table 4). However, a positive correlation between annual NAO and SW$_{Recirc.}$ CPI of *Fagus* was obtained (Table 4); this lack of consistency could be due to the cleaning effect of the precipitation (Frei, 1998; Jato et al., 2002; Peternel et al., 2004) during years with negative index that can mask the contributions of LRT. Frequency of the regional recirculation flows ranged between 19–

Please cite this article as: Izquierdo, R., et al., Is long range transport of pollen in the NW Mediterranean basin influenced by Northern Hemisphere teleconnection patterns?, Sci Total Environ (2015), http://dx.doi.org/10.1016/j.scitotenv.2015.06.047

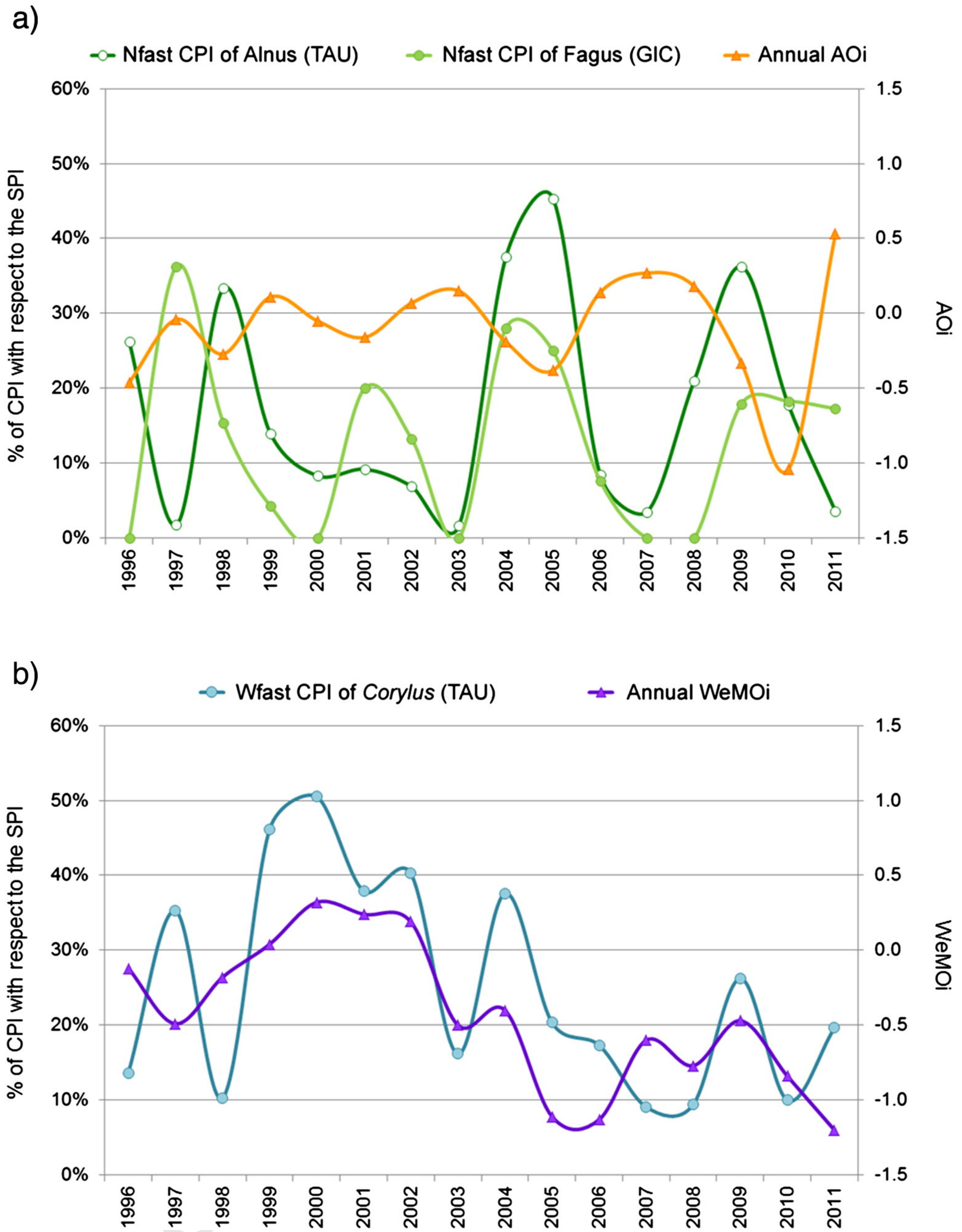


Fig. 3. Dynamics of a) annual AOi vs. percentage of *Alnus* pollen in the cluster Nfast (CPI) at Tarragona (TAU) and *Fagus* at Girona (GIC) with respect to the Seasonal Pollen Index (SPI) of each taxon; and b) annual WeMOi vs. percentage of *Corylus* pollen in the cluster Wfast at Tarragona with respect to the *Corylus* Seasonal Pollen Index for the 1996–2011 period.

38% of the pollen season of *Alnus*, *Betula*, *Corylus* and *Fagus* and accounted for 10–18% of their CPI (Table 3).

The LRT of *Fagus* from Western and Central Europe through N_{fast} and NE fluxes during the negative phase of annual NAO (Table 4) was highly significant because these provenances registered the 52% of its total CPI with a frequency of 21% during the *Fagus* (Table 3). Besides, a negative correlation between annual NAOi and NE CPI of *Corylus* was observed (Table 4), accounting for 11% of its total CPI (Table 3). These results are aligned with LRT of *Fagus* from Central Europe and *Corylus* from Northern Italy and South-Eastern France registered previously at Catalonia (Belmonte et al., 2008a,b). Conversely, the positive phase of annual NAO was associated with an intensification of *Alnus*, *Betula* and *Corylus* pollen transport from Western Iberian Peninsula by means of slow fluxes from SW (Table 4), despite its CPI values were low (4–10%) and its provenance frequencies ~10% (Table 3). Winter NAOi was also positively correlated with SW_{slow} CPI of *Corylus* (Table 4).

Negative correlations between annual AOi vs. N_{fast} CPI of *Alnus* and *Fagus* (Fig. 3a) and NW_{fast} of *Alnus* and *Corylus* (Table 4) indicated that LRT of *Alnus*, *Corylus* and *Fagus* from Western Europe may increase the years with negative index values. These provenances accounted for 24% of *Alnus* pollen season and 25% of its CPI, while low frequencies of fast-moving flows from N and NW during the *Corylus* and *Fagus* pollen season (7–9%) represented 10–16% of its total CPI (Table 3). On the other hand, LRT of *Alnus* from Western Iberian Peninsula (NW_{slow}), and *Corylus* and *Fagus* from Mediterranean (SE) area was associated with the positive phase of annual AO (Table 4), in spite of the low *Fagus* pollen content in the SE CPI (4%) (Table 3). These results are according with previous episodes of LRT of *Corylus* from Mediterranean area registered in this area (Belmonte et al., 2008b).

An increase of the *Ambrosia* levels produced by fast moving air-masses from the N coming from France and Northern Europe is expected during years with positive phase of winter WeMO, as well as from NE

Please cite this article as: Izquierdo, R., et al., Is long range transport of pollen in the NW Mediterranean basin influenced by Northern Hemisphere teleconnection patterns?, Sci Total Environ (2015), http://dx.doi.org/10.1016/j.scitotenv.2015.06.047

masses coming from Central and Eastern Europe is expected during the negative phase (Table 4). It should be noted that NE fluxes recorded the 35% of its total CPI with a frequency of 10% during the *Ambrosia*, while N_{fast} frequency accounted for 10% and represented only 7% of its total CPI (Table 3). These results are according with LRT of pollen from eastern France, Northern Italy, Hungary and Serbia regions, where *Ambrosia* is widely widespread, detected previously at Catalonia (Belmonte et al., 2000; Fernández-Llamazares et al., 2012). Negative correlations with winter WeMOi for *Betula* and *Fagus* linked to European fluxes from the NE (Table 4) could be due to an increase of the easterly winds linked to the negative phase of this index. High *Betula* and *Fagus* pollen content (29–36% of their CPI) was detected in the European provenance, which showed a frequency of 12% of both pollen season (Table 3). As commented before, LRT of *Fagus* from Europe was also detected in previous studies carried on Catalonia (Belmonte et al., 2008a,b). Finally, regional transport of *Corylus* from Western Iberian Peninsula was linked with the positive phase of annual WeMO (Fig. 3b).

5. Conclusions

The Mediterranean region is considered as one of the most vulnerable regions to climate change. The link between the synoptic meteorology and the Northern Hemisphere teleconnection patterns in the Western Mediterranean Basin showed in this study may be of primary importance. Specially, taking into account the upward trend of NAO and AO detected since the early 1970s. A number of authors have studied the influence exerted by the Northern Hemisphere teleconnection patterns on the plant phenology based on pollen counts at Europe. However this is the first study that has been devoted to analyzing their effect on atmospheric pollen transport. *Alnus*, *Ambrosia*, *Betula*, *Corylus* and *Fagus* were selected as allergenic pollen taxa with possible LRT associated to Northern Hemisphere teleconnection patterns in the Western Mediterranean Basin. Our results point out that an increase of LRT of *Alnus*, *Corylus* and *Fagus* pollen from Western and Central Europe may occur during the negative phase of annual NAO and AO, as well as regional transport of *Alnus*, *Betula* and *Corylus* from Western Iberian Peninsula during the positive phase. LRT of *Corylus* and *Fagus* from Mediterranean area was also associated with the positive phase of annual AO. In addition, LRT episodes of *Ambrosia* pollen from France and Northern Europe may take place when the phase of winter WeMO is positive, and from Central and Eastern Europe is expected during the negative phase. An increase of the *Betula* and *Fagus* levels linked to European fluxes may be ensued during years with negative phase of winter WeMO, as well as regional transport of *Corylus* from Western Iberian Peninsula during the positive phase of annual WeMO. Considering that *Alnus*, *Ambrosia*, *Betula* and *Corylus* pollen are among the most allergenic pollen taxa of Europe, sporadic episodes of allergy may be associated with these situations.

Finally, the atmospheric pollen transport depends on the phenology in source pollen areas and the variability of circulation patterns, which varies spatially and temporally. Therefore, further research is needed at regional scale in order to well-understand the influence of the Northern Hemisphere teleconnection patterns on pollen transport at different spatial levels and evaluate their potential impact on the public health.

Q5 6. Uncited reference

Hurrell and National Center for Atmospheric Research Staff, 2014

Q6 Acknowledgments

We acknowledge the financial support from European Commission for "ENV4-CT98-0755"; the Spanish Government for "AMB97-0457-CO7-021", "REN2001-10659-CO3-01", "CGL2004-21166-E", "CGL2005-07543/CLI", "CGL2009-11205", "CGL2012-39523-C02-01/CLI", CGL2012-39523-C02-02 and CONSOLIDER GRACCIE; the Catalan Government AGAUR for "2002SGR00059", "2005SGR00519", "2009SGR1102" and 2014SGR1274; Diputació de Tarragona, Servei Meteorològic de Catalunya, Sociedad Española de Alergología e Inmunología Clínica (SEAIC), División de Alergia de Laboratorios LETI S.L. Barcelona, Societat Catalana d'Al·lèrgia i Immunologia Clínica (SCAIC), Stallergenes Ibérica, S.A., J Uriach y Compañia, S.A., LAFOSCA STUDIO SL, Fundació Catalunya-La Pedrera. Javier Martín-Vide and Joan Albert López-Bustins, Group of Climatology (University of Barcelona), are thanked for WeMOi data, and Mirna Lopez for the assistance with back-trajectories analysis.

References

Ambaum, M.H.P., Hoskins, B.J., Stephenson, D.B., 2001. Arctic oscillation or North Atlantic Oscillation? J. Clim. 14, 3495–3507.

Andersen, T.B., 1991. A model to predict the beginning of the pollen season. Grana 30, 269–275.

Atkinson, M.D., Kettlewell, P.S., Hollins, P.D., Stephenson, D.B., Hardwick, N.V., 2005. Summer climate mediates UK wheat quality response to winter North Atlantic Oscillation. Agric. For. Meteorol. 130, 27–37.

Belmonte, J., Vendrell, M., Roure, J.M., Vidal, J., Botey, J., Cadahía, A., 2000. Levels of *Ambrosia* pollen in the atmospheric spectra of Catalan aerobiological stations. Aerobiologia 16, 93–99.

Belmonte, J., Alarcón, M., Avila, A., Scialabba, E., Pino, D., 2008a. Long-range transport of beech (*Fagus sylvatica* L.) pollen to Catalonia (north-eastern Spain). Int. J. Biometeorol. 52, 675–687.

Belmonte, J., Alarcón, M., Avila, A., Izquierdo, R., Cuevas, E., 2008b. Foreign allergenic pollen. Some cases observed in Catalonia (NE Spain) and Tenerife (Canary Islands). Allergy 63 (Suppl. 88), 104–105.

Bladé, I., Liebmann, B., Fortuny, D., Jan van Oldenborgh, G., 2012. Observed and simulated impacts of the summer NAO in Europe: implications for projected drying in the Mediterranean region. Clim. Dyn. 39, 709–727.

Cape, J.N., Methven, J., Hudson, L.E., 2000. The use of trajectory cluster analysis to interpret trace gas measurements at Mace Head, Ireland. Atmos. Environ. 34, 3651–3663.

D'Odorico, P., Yoo, J., Jaeger, S., 2002. Changing seasons: an effect of the North Atlantic Oscillation. J. Clim. 15, 435–445.

Dalla Marta, A., Grifoni, D., Torrigiani Malaspina, T., Cecchi, L., Barbano, F., Mancini, M., Orlandini, S., 2011. The effects of large-scale atmospheric fields on the cypress pollen season in Tuscany (Central Italy). Aerobiologia 27, 213–220.

Damialis, A., Gioulekas, D., Lazopoulou, C., Balafoutis, C., Vokou, D., 2005. Transport of airborne pollen into the city of Thessaloniki: the effects of wind direction, speed and persistence. Int. J. Biometeorol. 49 (3), 139–145.

Dorling, S.R., Davies, T.D., 1995. Extending cluster analysis — synoptic meteorology links to characterise chemical climates at six north-west European monitoring stations. Atmos. Environ. 29 (2), 145–167.

Draxler, R.R., Rolph, G.D., 2003. HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY website (http://www.arl.noaa.gov/ready/hysplit4.html). NOAA Air Resources Laboratory, Silver Spring, MD.

Draxler, R.R., Stunder, B., Rolph, G., Taylor, A., 2009. HYSPLIT_4 User's Guide. NOAA Air Resources Laboratory (http://www.arl.noaa.gov/documents/reports/hysplit_user_guide.pdf).

Dünkeloh, A., Jacobeit, J., 2003. Circulation dynamics of Mediterranean precipitation variability 1948–98. Int. J. Climatol. 23, 1843–1866.

Fernández-Llamazares, A., Belmonte, J., Alarcón, M., López-Pacheco, M., 2012. *Ambrosia* L. in Catalonia (NE Spain): expansion and aerobiology of a new bioinvader. Aerobiologia 28, 435–451.

Frei, T., 1998. The effects of climate change in Switzerland 1969–1996 on airborne pollen quantities from hazel, birch and grass. Grana 37, 172–179.

Galán Soldevilla, C., Cariñanos González, P., Alcázar Teno, P., Domínguez Vilches, E., 2007. Manual de Calidad y Gestión de la Red Española de Aerobiología. Servicio de Publicaciones, Universidad de Córdoba.

Giorgi, F., 2006. Climate change hot-spots. Geophys. Res. Lett. 33, L08707.

Gonzalez-Hidalgo, J.C., Lopez-Bustins, J.A., Štepánek, P., Martin-Vide, J., de Luis, M., 2009. Monthly precipitation trends on the Mediterranean fringe of the Iberian Peninsula during the second-half of the twentieth century (1951–2000). Int. J. Climatol. 29, 1415–1429.

Goodess, C.M., Jones, P.D., 2002. Links between circulation and changes in the characteristics of Iberian rainfall. Int. J. Climatol. 22, 1593–1615.

Hernández-Ceballos, M.A., García-Mozo, H., Adame, J.A., Domínguez-Vilches, E., De la Morena, B.A., Bolívar, J.P., Galán, C., 2011. Synoptic and meteorological characterization of olive pollen transport in Cordoba province (South-western Spain). Int. J. Biometeorol. 55, 17–34.

Hernández-Ceballos, M.A., Skjøth, C.A., García-Mozo, H., Galán, C., 2014. Improvement in the accuracy of back trajectories using WRF to identify pollen sources in southern Iberian Peninsula. Int. J. Biometeorol. 58, 2031–2043.

Hirst, J.M., 1952. An automatic volumetric spore trap. Ann. Appl. Biol. 39, 257–265.

Hurrell, J.W., 1995. Decadal trend in the North-Atlantic Oscillation — regional temperatures and precipitation. Science 269, 676–679.

Hurrell, James & National Center for Atmospheric Research Staff (Eds). Last modified 05 Sep 2014. "The Climate Data Guide: Hurrell North Atlantic Oscillation (NAO) Index (station-based)." Retrieved from https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based. Q7

Please cite this article as: Izquierdo, R., et al., Is long range transport of pollen in the NW Mediterranean basin influenced by Northern Hemisphere teleconnection patterns?, Sci Total Environ (2015), http://dx.doi.org/10.1016/j.scitotenv.2015.06.047

IPCC, 2007. Climate change 2007. The physical science basis. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA (996 pp.).

Izquierdo, R., Belmonte, J., Àvila, A., Alarcón, M., Cuevas, E., Alonso-Pérez, S., 2011. Source areas and long-range transport of pollen from continental land to Tenerife (Canary Islands). Int. J. Biometeorol. 55, 67–85.

Izquierdo, R., Avila, A., Alarcón, M., 2012. Trajectory statistical analysis of atmospheric transport patterns and trends in precipitation chemistry of a rural site in NE Spain in 1984–2009. Atmos. Environ. 61, 400–408.

Izquierdo, R., Aguillaume, L., Alarcón, M., Avila, A., 2014. Effects of teleconnection patterns on the atmospheric routes, precipitation amount and chemistry in the north-eastern Iberian Peninsula. Atmos. Environ. 89, 482–490.

Q8 Izquierdo, R., Alarcón, M., Majeed, H.T., Periago, C., Belmonte J. Unpublished results. Influence of the climate variability on the airborne pollen levels recorded in Catalonia (NW Mediterranean). *Submitted to Sci. Total Environ.*

Jato, V., Méndez, J., Rodríguez-Rajo, J., Seijo, C., 2002. The relationship between the flowering phenophase and airborne pollen of Betula in Galicia (N.W. Spain). Aerobiologia 18, 55–64.

Jochner, S., Menzel, A., 2015. Does flower phenology mirror the slowdown of global warming? Ecol. Evol. http://dx.doi.org/10.1002/ece3.1503.

Jorba, O., Pérez, C., Rocadensbosch, F., Baldasano, J.M., 2004. Cluster analysis of 4-day back trajectories arriving in the Barcelona area, Spain, from 1997 to 2002. J. Appl. Meteorol. 43, 887–901.

Krichak, S.O., Breitgand, J.S., Gualdi, S., Feldstein, S.B., 2014. Teleconnection-extreme precipitation relationships over the Mediterranean region. Theor. Appl. Climatol. 117, 679–692.

Lopez-Bustins, J.A., Martín-Vide, J., Sanchez-Lorenzo, A., 2008. Iberia Winter rainfall trends based upon changes in teleconnection and circulation patterns. Glob. Planet. Chang. 63, 171–176.

Makra, L., Santa, T., Matyasovszky, I., Damialis, A., Karatzas, K., Bergmann, K.C., Vokou, D., 2010. Airborne pollen in three European cities: detection of atmospheric circulation pathways by applying three-dimensional clustering of backward trajectories. J. Geophys. Res. Atmos. 115, D24220.

Markou, M.T., Kassomenos, P., 2010. Cluster analysis of five years of back trajectories arriving in Athens, Greece. Atmos. Res. 98, 438–457.

Marshall, J., Kushnir, Y., Battisti, D., Chang, P., Czaja, A., Dickson, R., et al., 2001. North Atlantic climate variability: phenomena, impacts and mechanisms. Int. J. Climatol. 21 (15), 1863–1898.

Martín-Vide, J., Lopez-Bustins, J.A., 2006. The Western Mediterranean Oscillation and rainfall in the Iberian Peninsula. Int. J. Climatol. 26 (11), 1455–1475 (Website: http://www.ub.edu/gc/English/wemo.htm).

Menzel, A., Sparks, T.H., Estrella, N., Koch, E., Aasa, A., Ahas, R., et al., 2006. European phenological response to climate change matches the warming pattern. Glob. Chang. Biol. 12 (10), 1969–1976.

Millán, M., Salvador, R., Mantilla, E., Kallos, G., 1997. Photo-oxidant dynamics in the Mediterranean basin in summer: results from European research projects. J. Geophys. Res. 102, 8811–8823.

Mysterud, A., Stenseth, N.C., Yoccoz, N.G., Ottersen, G., Langvatn, R., 2003. The response of terrestrial ecosystems to climate variability associated with the North Atlantic Oscillation. In: Hurrell, J.W., Kushnir, Y., Ottersen, G., Visbeck, M. (Eds.), The North Atlantic Oscillation. American Geophysical Union, Washington, DC, pp. 235–262.

Ottersen, G., Planque, B., Belgrano, A., Post, E., Reid, P.C., Stenseth, N.C., 2001. Ecological effects of the North Atlantic Oscillation. Oecologia 128, 1–14.

Peternel, R., Srnec, L., Culig, J., Zaninovic, K., Mitic, B., Vukusic, I., 2004. Atmospheric pollen season in Zagreb (Croatia) and its relationship with temperature and precipitation. Int. J. Biometeorol. 48, 186–191.

Prank, M., Chapman, D.S., Bullock, J.M., Belmonte, J., Berger, U., Dahl, A., et al., 2013. An operational model for forecasting ragweed pollen release and dispersion in Europe. Agric. For. Meteorol. 182–183, 43–53.

Rodríguez, S., Querol, X., Alastuey, A., Mantilla, E., 2003. Events affecting levels and seasonal evolution of airborne particulate matter concentrations in the Western Mediterranean. Environ. Sci. Technol. 37, 216–222.

Salvador, P., Artíñaño, B., Querol, X., Alastuey, A., Costoya, M., 2007. Characterisation of local and external contributions of atmospheric particulate matter at a background coastal site. Atmos. Environ. 41, 838–845.

Salvador, P., Artíñano, B., Querol, X., Alastuey, A., 2008. A combined analysis of backward trajectories and aerosol chemistry to characterise long-range transport episodes of particulate matter: the Madrid air basin, a case of study. Sci. Total Environ. 390, 495–506.

Sharma, S., 1996. Applied Multivariate Techniques. John Wiley & Sons, Inc., New York, p. 493.

Skjøth, C.A., Smith, M., Brandt, J., Emberlin, J., 2009. Are the birch trees in southern England a source of Betula pollen for North London? Int. J. Biometeorol. 53 (1), 75–86.

Skjøth, C.A., Šikoparija, B., Jäger, S., EAN-Network, 2012. Pollen sources. In: Sofiev, M., Bergman, K.-C. (Eds.), A Review of Production, Release, Distribution and Health Impact of Allergenic Pollen. Springer, pp. 9–27 (Chapter 2).

Smith, M., Skjøth, C.A., Myszkowska, D., Uruska, A., Puc, M., Stach, A., et al., 2008. Long-range transport of Ambrosia pollen to Poland. Agric. For. Meteorol. 14, 1402–1411.

Smith, M., Emberlin, J., Stach, A., Rantio-Lehtimäki, A., Caulton, E., Thibaudon, M., et al., 2009. Influence of the North Atlantic Oscillation on grass pollen counts in Europe. Aerobiologia 25, 321–332.

Stach, A., Smith, M., Prieto Baena, J.C., Emberlin, J., 2008a. Long-term and short-term forecast models for Poaceae (grass) pollen in Poznań, Poland, constructed using regression analysis. Environ. Exp. Bot. 62, 323–332.

Stach, A., Emberlin, J., Smith, M., Adams-Groom, B., Myszkowska, D., 2008b. Int. J. Biometeorol. 52, 311–321.

Stenseth, N.C., Mysterud, A., Ottersen, G., Hurrel, J.W., Chan, K.S., Lima, M., 2002. Ecological effects of climate fluctuations. Science 297, 1292–1296.

Straile, D., Stenseth, N.C., 2007. The North Atlantic Oscillation and ecology: links between historical time-series, and lessons regarding future climate warming. Clim. Res. 34, 259–262.

Thompson, D.W.J., Wallace, J.M., 1998. The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. Geophys. Res. Lett. 25, 297–1300.

Thompson, D.W.J., Wallace, J.M., 2000. Annular modes in the extratropical circulation. Part I: month-to-month variability. J. Clim. 13, 1000–1016.

Torben, B.A., 1991. A model to predict the beginning of the pollen season. Grana 30, 269–275.

Ulbrich, U., Lionello, P., Berlušić, D., Jacobeit, J., Knippertz, P., Kuglitsch, F.G., et al., 2012. Climate of the Mediterranean: synoptic patterns, temperature, precipitation, winds, and their extremes. In: Lionello, P. (Ed.), The Climate of the Mediterranean Region, From the Past to the Future. Elsevier, Dordrecht, pp. 301–346.

Valenzuela, A., Olmo, F.J., Lyamani, H., Antón, M., Quirantes, A., Alados-Arboledas, L., 2012. Classification of aerosol radiative properties during African desert dust intrusions over southeastern Spain by sector origins and cluster analysis. J. Geophys. Res. 117, D06214.

Veriankaite, L., Siljamo, P., Sofiev, M., Sauliene, I., Kukkonen, J., 2010. Modelling analysis of source regions of long-range transported birch pollen that influences allergenic seasons in Lithuania. Aerobiologia 26, 47–62.

Visbeck, M.H., Hurrell, J.W., Polvani, L., Cullen, H.M., 2001. The North Atlantic Oscillation: past, present and future. Proc. Natl. Acad. Sci. U. S. A. 98, 12876–12877.

Wallace, J.M., 2000. North Atlantic oscillatiodannular mode: two paradigms — one phenomenon. Q. J. R. Meteorol. Soc. 126, 791–805.

Wallace, J.M., Gutzler, D.S., 1981. Teleconnections in the geopotential height field during the Northern Hemisphere winter. Mon. Weather Rev. 109, 784–812.

Zemmer, F., Karaca, F., Ozkaragoz, F., 2012. Ragweed pollen observed in Turkey: detection of sources using back trajectory models. Sci. Total Environ. 430, 101–108.

Please cite this article as: Izquierdo, R., et al., Is long range transport of pollen in the NW Mediterranean basin influenced by Northern Hemisphere teleconnection patterns?, Sci Total Environ (2015), http://dx.doi.org/10.1016/j.scitotenv.2015.06.047